Comparative survey of ultrasound images compression methods dedicated to a tele-echography robotic system

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Summary - **This paper proposes an evaluation of various compression techniques, for ultrasound images transmission, within a telemedicine project. For the purpose of this work, we selected seven compression methods : Fourier Transform, Discrete Cosine Transform, Wavelets, Quadtrees Transform, Fractals, Histogram Thresholding, and Run Lenght Coding. Preliminary results obtained on echographic images show that the method based upon the wavelet transform seems to give the best compromise between coding performance and image quality, measured thanks to mean square error and coding time.**

Keywords - **Ultrasound images, telemedicine, image compression**

I. INTRODUCTION

This paper presents a comparison among ultrasound images compression methods dedicated to a tele-scanning robotic system. That is part of the TER project, described in [1].

The TER project has for objective to allow an ultrasonographer expert to achieve an exam from afar.

The TER telemedicine chain (Fig1), currently being developed by the TER consortium including our laboratory, comprises a master station, where the ultrasound specialist handles a fictive probe with a 3D sensor, and a slave station that includes a probe holder robot which moves the real probe according to the fictive probe motions [1]. The echographic images are captured by an ultrasound scan device, and sent to the master station via standard communication link (e.g. satellite, ISDN…).

Slave station with ultrasound device

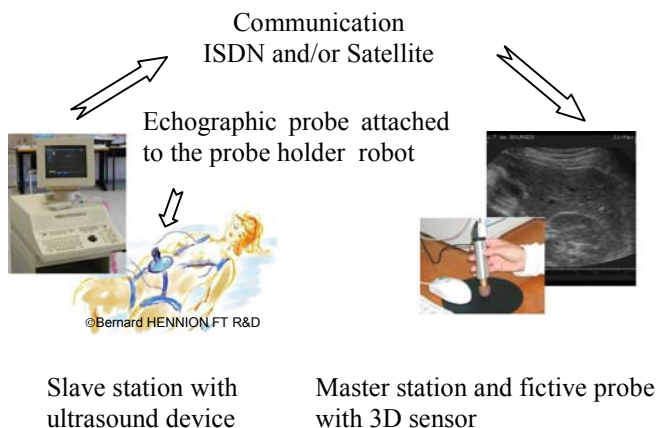Master station and fictive probe with 3D sensor

Fig. 1. TER telemedicine chain

The feasibility of this remotely tele-operated ultrasound probe was demonstrated during the "SHISHA 98" experimentation whose main objective was to achieve a tele-echography between Bourges (France) and Katmandu (Nepal), thanks to a satellite communication [2] [3]. For this mission, a specific ultrasound image treatment module was developed. It was composed of three successive stages: the selection of a region of interest, the scaling of this region to 16 gray levels, and finally a LZH coding (Lempel-Ziv-Huffman).

Following this successful experience, one of the major improvements concerning the image transmission technique was to achieve an analysis on the images compression part.

For tele-operated systems such as in the TER project, where emergency telemedicine is one of the foreseen applications, image compression is an essential step, especially for the improvement of the real-time transmission and control of the probe holder robot. Therefore, when using standard communication system or high bandwidth and rates links for the tele-operated robot, it becomes a necessity to optimize the images transmission time while preserving the best quality to best assist the clinical expert diagnosis.

This comparative study on compression techniques, dedicated to ultrasound images, is proposed in order to extract the best method that gives an optimal transmission time and the best image quality for the ultrasound specialist.

Part II of this article presents the tested compression methods. Part III describes the experimental protocol of our survey. The experimental results are developed and are discussed in parts IV and V. Conclusion and perspectives of our work are exposed in part VI.

II. COMPRESSION METHODS

Current process of image compression is composed of three sequences. Decorrelation, based on inter-pixel dependence, reduces the volume of information. Quantization reduces the number of necessary bits in order to keep the significant coefficient values. Finally, coding leads to a binary stream.

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Abstract

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Quantization is the only stage that generates information losses, giving an lossy compression. Medical imagery sets, in this sense, a crucial problem: what is the relevant information and where is it in the grabbed image ?

Therefore, we chose techniques that solely take advantages of the interrelationship in the image, and decided to avoid quantification.

Compression methods can be classified in two categories:

On the one hand, Pixel Coding methods analyze the image locally, that is to say pixel by pixel. Their concept is to search for the information redundancy in the image, and to perform a reduced coding. Each of these methods is based on information theory. We can mention the orthogonal transforms (e.g. Fourier Transform, Discrete Cosine Transform) [4]. Their concept is to redistribute the image energy in a restricted number of transformation coefficients. These transformations are used most the time in lossy compression methods, as they are associated to a quantization stage (as it is the case for the JPEG method). In our case to avoid loss of information, we did not use the quantization stage, but we disregarded coefficients of very low values.

On the other hand, Global Coding methods extract information according to the global features of the image. These methods include hierarchical methods, subband coding system (e.g. Fractals [5], Quadtrees [6]), and decompositions in filter banks (e.g. Wavelets [7]), and the segmentation methods shape/texture (e.g. the histogram thresholding [8]). These techniques exploit the similarities within a image, and thus allows to get higher compression rates.

The statistical coding methods generally constitute the final stage of a compression technique. They are lossless and code according to the occurrence frequency of a symbol present in a whole image. The most popular statistical codes are Huffman, Lempel-Ziv and Shannon-Fanos. In spatial coding, one can also mention the RLE coding (Run Length Coding) [4].

III. EXPERIMENTAL PROTOCOL

The survey was performed on 10 ultrasound images of size 512*512 pixels similar to the one shown in Fig 2. These images have been acquired by an AU3 ultrasound scanner (ESAOTE) at a 15 images per second frequency, then digitized thanks to a Matrox Meteor board.

The algorithms software have been programmed in Matlab 5.3. code, the toolbox are those of MathWorks, and WaveLab version 8.02 [9]. The experiments are achieved by a Pentium III with 450 MHz, under Windows 98.

Fig. 2. Ultrasound Image of a liver

We have selected these different compression methods :

1. The Fourier Transform (FT) [4],
2. The Discrete Cosine Transform (DCT) [4],
3. The Quadtree decomposition (Q) [6],
4. The Wavelets Transform with three distinct filters – Coiflets (WTC), Daubechies (WTD) and Symmlet (WTS) [7],
5. The Fractals (F) [5],
6. The Histogram Thresholding (HT) [8],
7. The Run Length Coding (RLE) [4].

Each image has been coded then decoded by each of these proposed methods at various compression rates.

These techniques were compared according to different criteria for a given compression rate: the mean square error, the peak signal to noise ratio between the original image and the rebuilt image, and times of compression and decompression.

. The compression rate (CR) represents the number of bits before compression over number of bit after compression

. The mean square error (MSE)

$$MSE^2 = \sum_i \sum_j (New_{ij} - Original_{ij})^2 \Big/ I \times J$$

measures the distortion brought by the compression. It is defined by the mean of the square distances between every pixel *(i,j)* of the original image $Original_{ij}$ and each pixel of the rebuilt image New_{ij}.

. The peak signal to noise ratio PSNR

$$PSNR = 10 \log_{10} IMax^2 \Big/ \sqrt{MSE^2}$$

represents an unbiased measure of the fidelity of the rebuilt image. More precisely, it represents the MSE, referenced with respect to the dynamics of the image in decibels ($IMax^2$ is the maximal intensity).

The bigger the PSNR is, the smaller the MSE gets, the better is the rebuilt image quality (that is to say "faithful" to the original image).

. Times of compression (CT) and decompression (DT) are an important factor for our tele-operated system as delays could hinder the control of the distant robot and therefore the accuracy in the image acquisition. At the master station site, the clinical expert tele-operates the distant robot by holding a fictive probe. He visualizes in real time the distant patient ultrasound images on a control screen. The reduction of images transmission delay time, by improving compression techniques, is thus a necessity for the specialist as ultrasound examination require good hand-to-eye co-ordination and the ability to integrate the acquired information over time and space.

IV. RESULTS

We compare these techniques with the following criteria : measure of the rebuilt image quality, and the coding computer time.

Fig.3 shows the comparison between the different techniques according to the MSE with respect to CR.

We can see on Fig.4 the PSNR measured for the seven methods. This criterion is said to be good, when it is less than 30 dB.
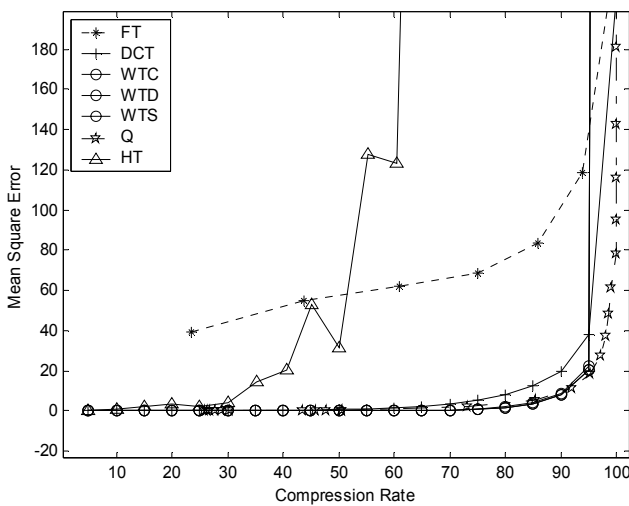

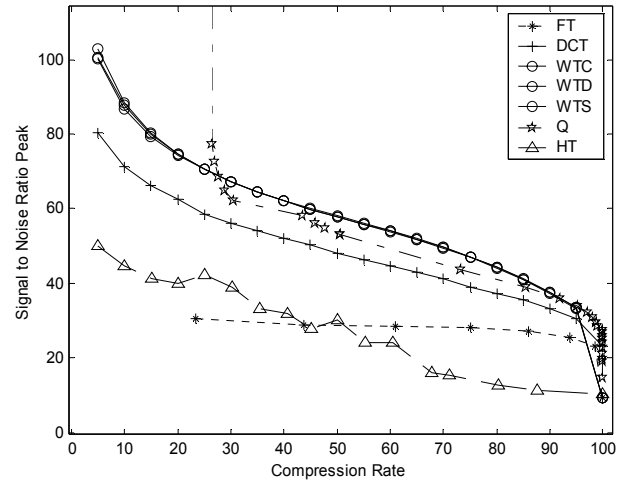Fig. 3. Comparison between MSE and CR

Fig. 4. Comparison between PSNR and CR

Table I shows the comparison results for a given compression rate.

TABLE I
COMPARISON RESULTS FOR ONE GIVEN CR (50%)

Methods	CT (in s)	DT (in s)	MSE	PSNR (in dB)
FT	6. 12	2.37	54.95	28.96
DCT	35.64	3,74	0.69	47.93
Q	4.39	1.67	0.21	53.11
WTC	**6.92**	**5.29**	**0.07**	**57.98**
WTD	6.79	5.17	0.07	57.90
WTS	6.72	5.12	0.07	57.85
F	9966 (2 h)	752 (12 mn)	5360	10
HT	0.16	0.05	31.49	30.07

These results represent an average measure of the MSE, PSNR and coding computed time calculated on ten rebuilt and original images of our database.

As we expected, the results given by the lossless RLE method are not suited to ultrasound images, as they are usually very corrupted by noise. For instance, to code 262144 values (512*512 pixels), the RLE required a minimum of 190000 pair of values (*{gray level, number of repetitions}*), therefore increasing needlessly the quantity of information and computation time.

V. DISCUSSION

The three types of WT filters (Coiflet, Daubechies and Symmlet) give similar results when considering all the chosen criteria. For now on, we will refer to global wavelets transforms WT without discriminating the filters used.

From Table I, it can be immediately concluded that the Fractals method is not appropriate for ultrasound images.

Fig.3 et Fig.4 show that WT, DCT and Q methods present the lowest MSE (closed to zero), which is a very good property for image quality up to high compression rates of about 80%, and the highest PSNR (greater than 30 dB, that is our quality criterion low limit) among all the used techniques and for the whole compression range. DCT method needs a large computation time of 35.64 s for a 50% compression step (Table I). It is therefore not appropriate for a real-time control of the robot. WT present a higher PSNR than Q of about 4 dB, hence giving a better image quality, moreover there is no block effect due to the WT procedure.

The HT technique do not alter the image quality when using a low compression rate inferior to 30%, and present the shortest computation time of 0.16s. It will be the first step of the compression sequence.

With satisfying compression and decompression times, the FT method does not give a good image quality with a 28.96 dB PSNR and a 54.95 MSE.

VI. CONCLUSION & PERSPECTIVES

A) Conclusion

The goal of this survey was to determine the best compression method dedicated to ultrasound images for a tele-scanning robotic system.
We tested seven techniques, based on pixel coding and global coding methods. We compared them based on the following criteria : the rebuilt image quality (given by mean square error and signal to noise ratio) and the compression and decompression times.

Experimental results performed on ten ultrasound images establish that the wavelets transform (WT) seems to be the best method for our tele-medicine application. Indeed, this method gives the best compromise between the image quality, the compression rate and the coding time. It satisfies our needs for our real-time tele-operated robotic system.

Moreover, the histogram thresholding (HT) method reveals to be very interesting for compression rate lower than 30%. This technique is very fast and give a good image quality. We will use this method in the first step of our compression system.

B) Perspectives

This test can not be performed on the color pictures. One of improvements will be to take into account the three RGB image.

The proposed techniques are not optimized yet, but offer a certain evolution possibility. Therefore, we can foresee an improvement of compression rates while preserving the image quality as well as the image transfer duration between the slave station and the master station.

Furthermore, for future experiments, another step will be added in the compression chain. This will be the selection of a region of interest in the acquired ultrasound image. We will test this complementary step capacity to improve the compression performance, and eventually by reducing the coding time.

In order to measure the transmitted images quality and to validate the chosen method, we consider to perform an analysis of diagnosis fidelity. For this purpose, we will use the R.O.C.S. curves methodology (Receiver Operator Characteristics), and psychovisual methods.
We wish to widen our survey with ultrasound sequences video, while testing techniques of movement compensation, and MPEG compression.

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